

## AMENDED CLAIMS

[received by the International Bureau on 12 February 2004 (12.02.04);  
original claims 1 and 10 amended; remaining claims unchanged]

- 1 1. A nuclear magnetic resonance (NMR) logging apparatus for use in a  
2 borehole for determining properties of an earth formation surrounding the  
3 borehole, the apparatus comprising:  
4 (a) a magnet for inducing a static magnetic field in a region of interest in  
5 the earth formation;  
6 (b) a transmitting antenna assembly for inducing a radio frequency  
7 magnetic field within said region of interest and producing signals  
8 from materials in the region of interest; and  
9 (c) a receiving antenna assembly for detecting said signals from said  
10 region of interest;  
11 wherein at least one of the antenna assemblies includes at least one magnetic  
12 core formed from a non-ferritic material having low magnetostriction.  
13
- 1 2. The NMR logging apparatus of claim 1 wherein said material has a  
2 high internal damping and further comprises a powdered soft magnetic  
3 material.  
4
- 1 3. The NMR logging apparatus of claim 2 wherein the powdered soft magnetic  
2 material is non-conductive and has a maximum grain size to  
3 substantially reduce intragranular power loss at a frequency of said radio  
4 frequency magnetic field.  
5
- 1 4. The NMR logging apparatus of claim 2 wherein the powdered soft  
2 magnetic material has a maximum grain size less than half the wavelength of an  
3 acoustic wave having a frequency of said radio frequency magnetic field.  
4
- 1 5. The NMR logging apparatus of claim 1 wherein said material has a  
2 high internal damping and further has a large area within a hysteresis loop  
3 associated with magnetostrictive deformation of the material.  
4
- 1 6. The NMR logging apparatus of claim 2 wherein said at least one antenna

core further comprises a non-conductive bonding agent having substantial acoustic decoupling between grains.

7. The NMR logging apparatus of claim 1 wherein said logging apparatus is adapted to be conveyed on one of (i) a wireline, and, (ii) a drilling tubular.

8. The NMR logging apparatus of claim 1 wherein said material has a low magnetostriction and comprises an amorphous metal.

9. The NMR logging apparatus of claim 1 wherein the transmitting antenna assembly and the receiving antenna assembly are the same.

10. A method of determining properties of an earth formation surrounding a borehole, the method comprising:

- (a) using a magnet on a nuclear magnetic resonance (NMR) logging apparatus conveyed in the borehole for inducing a static magnetic field in a region of interest in the earth formation;
- (b) using a transmitting antenna assembly for inducing a radio frequency magnetic field within said region of interest and producing signals from materials in the region of interest; and
- (c) using a receiving antenna assembly for detecting said signals from said region of interest;

the method further comprising using a core for at least one of the antenna assemblies formed from a non ferritic material having low magnetostriction.

11. The method of claim 10 wherein said material has a high internal damping, the method further comprising using a powdered soft magnetic material as said material with high internal damping.

12. The method of claim 11 further comprising selecting the powdered soft magnetic material to be substantially non-conductive and having a maximum

- 3 grain size to substantially reduce intragranular power loss at a frequency of  
4 said radio frequency magnetic field.  
5
- 1 13. The method of claim 11 further comprising selecting the powdered soft  
2 magnetic material as having a maximum grain size less than half a  
3 wavelength of an acoustic wave having a frequency of said radio frequency  
4 magnetic field.  
5
- 1 14. The method of claim 10 wherein said material has high internal damping, the  
2 method further comprising selecting said material as having a large area  
3 within a hysteresis loop associated with magnetostrictive deformation of the  
4 material.  
5
- 1 15. The method of claim 11 further comprising using in said at least one antenna  
2 core a non-conductive bonding agent having substantial acoustic decoupling  
3 between grains.  
4
- 1 16. The method of claim 10 further comprising conveying said NMR logging  
2 apparatus into said borehole on one of (i) a wireline, and, (ii) a drilling  
3 tubular.  
4
- 1 17. The method of claim 10 wherein said material has a low magnetostriction, the  
2 method further comprising selecting an amorphous metal for use as said  
3 material.  
4
- 1 18. The method of claim 10 further comprising using the same antenna for the  
2 transmitting antenna and the receiving antenna.  
3
- 1 19. An apparatus for evaluating electrical properties of an earth formation  
2 surrounding a borehole, the apparatus comprising:  
3 (a) a transmitting antenna assembly for conveying a radio frequency

- 4 electromagnetic field into said earth formation; and  
5 (b) a receiving antenna assembly for receiving a signal resulting from  
6 interaction of said electromagnetic field with said earth formation;  
7 wherein at least one of the antenna assemblies includes at least one of: (I) a  
8 magnetic core formed from a material having high internal magnetostrictive  
9 damping, and, (II) low magnetostriction.  
10
- 1 20. The apparatus of claim 19 wherein said material has a high internal damping  
2 and further comprises a powdered soft magnetic material.  
3
- 1 21. The apparatus of claim 20 wherein the powdered soft magnetic material is  
2 non-conductive and has a maximum grain size to substantially reduce  
3 intragranular power loss at a frequency of said radio frequency magnetic field.  
4
- 1 22. The apparatus of claim 20 wherein the powdered soft magnetic material has a  
2 maximum grain size less than half a wavelength of an acoustic wave having a  
3 frequency of said radio frequency magnetic field.  
4
- 1 23. The apparatus of claim 19 wherein said material has a high internal damping  
2 and further has a large area within a hysteresis loop associated with  
3 magnetostrictive deformation of the material.  
4
- 1 24. The apparatus of claim 20 wherein said at least one antenna core further  
2 comprises a non-conductive bonding agent having substantial acoustic  
3 decoupling between grains.  
4
- 1 25. The apparatus of claim 19 wherein said apparatus is adapted to be conveyed  
2 on one of (i) a wireline, and, (ii) a drilling tubular.  
3
- 1 26. The apparatus of claim 19 wherein said material has a low magnetostriction  
2 and comprises an amorphous metal.

3

1 27. A method of determining a resistivity parameter of an earth formation  
2 surrounding a borehole, the method comprising:

3 (a) using a transmitting antenna assembly on a tool conveyed in said  
4 borehole for transmitting a radio frequency electromagnetic field into  
5 said earth formation;

6 (b) using a receiving antenna assembly for receiving a signal resulting  
7 from interaction of said electromagnetic field with said earth  
8 formation;

9 (c) using a core for at least one of the antenna assemblies for enhancing  
10 the received signals, said core formed from a material having at least  
11 one of (I) high internal magnetostrictive damping, and, (II) low  
12 magnetostriction.

13

1 28. The method of claim 27 wherein said material has a high internal damping,  
2 the method further comprising using a powdered soft magnetic material as  
3 said material with high internal damping.

4

1 29. The method of claim 28 further comprising selecting the powdered soft  
2 magnetic material to be substantially non-conductive and having a maximum  
3 grain size to substantially reduce intragranular power loss at a frequency of  
4 said radio frequency magnetic field.

5

1 30. The method of claim 28 further comprising selecting the powdered soft  
2 magnetic material as having a maximum grain size less than half a wavelength  
3 of an acoustic wave having a frequency of said radio frequency magnetic  
4 field.

5

1 31. The method of claim 27 wherein said material has high internal damping, the  
2 method further comprising selecting said material as having a large area  
3 within a hysteresis loop associated with magnetostrictive deformation of the

4 material.

5

1 32. The method of claim 28 further comprising using in said at least one antenna  
2 core a non-conductive bonding agent having substantial acoustic decoupling  
3 between grains.

4

1 33. The method of claim 27 wherein said material has a low magnetostriction, the  
2 method further comprising selecting an amorphous metal for use as said  
3 material.

4

1 34. The method of claim 27 wherein said tool is conveyed into the borehole on  
2 one of (i) a wireline, and, (ii) a drilling tubular.

3

1 35. An apparatus for evaluating electrical properties of an earth formation  
2 surrounding a borehole, the apparatus comprising:

3 (a) a transmitting antenna assembly for conveying an electromagnetic  
4 field into said earth formation; and

5 (b) a receiving antenna assembly for receiving a signal resulting from  
6 interaction of said electromagnetic field with said earth formation;

7 wherein at least one of said antenna assemblies includes at least one magnetic  
8 core formed from a non-ferritic powdered soft magnetic material having high  
9 saturation flux density and a non-conductive bonding agent, said magnetic  
10 core having a magnetic permeability  $\mu_m$  less than 500 and wherein said  
11 saturation flux density is greater than about 0.4 T.

12

1 36. The apparatus of claim 35, wherein the magnetic core further comprising  
2 dimensions which are related to the direction of an RF magnetic field  
3 produced by the transmitter coil and to the magnetic permeability of the  
4 powdered soft magnetic material.

5

1 37. The apparatus of claim 35 wherein the powdered soft magnetic material is

- 2       conductive and has a maximum grain size to substantially prevent  
3       intragranular power loss of said transmitted electromagnetic signal.  
4
- 1   38.   The apparatus of claim 35 wherein an effective demagnetizing factor of the  
2       magnetic core in a direction of the radio frequency magnetic field  
3       substantially exceeds the inverse magnetic permeability of the powdered soft  
4       magnetic material.  
5
- 1   39.   The apparatus of claim 36, wherein the core has an effective permeability,  $\mu$ ,  
2       less than 5, as defined by a first equation,  
3       
$$\mu = 1 + (\mu_m - 1) / ((\mu_m - 1) \cdot D + 1),$$
  
4       wherein D, the demagnetizing factor can be estimated from an elliptic  
5       equivalent of the cross-section of the core, as defined by a second equation,  
6        $D = S_x / (S_x + S_y),$   
7       wherein  $S_x$  and  $S_y$  represent the elliptic equivalent dimensions in horizontal  
8       and vertical dimensions respectively, in a plane the core.  
9
- 1   40.   The apparatus as defined in claim 35 wherein the powdered soft magnetic  
2       material possesses a maximum magnetic permeability given a predetermined  
3       maximum RF antenna power loss.  
4
- 1   41.   The apparatus of claim 35 wherein said flux density is greater than that of a  
2       magnetic core consisting primarily of ferrite.  
3
- 1   42.   The apparatus of claim 35 wherein the magnetic core further comprises  
2       relative dimensions that are related to the direction of the RF magnetic field  
3       and to the magnetic permeability of the powdered soft magnetic material.  
4
- 1   43.   A method of making measurements of a parameter of interest of an earth  
2       formation comprising:  
3       (a)   conveying a logging tool into a borehole in said earth formation;

- 4 (b) using a transmitter antenna assembly on the logging tool for  
 5 conveying an electromagnetic field into the earth formation;  
 6 (c) using a receiver antenna assembly for detecting signals resulting from  
 7 interaction of said electromagnetic field with said earth formation, and  
 8 (d) including in at least one of the antenna assemblies a magnetic core  
 9 formed from a non-ferritic powdered soft magnetic material having  
 10 high saturation flux density and a non-conductive bonding agent, said  
 11 magnetic core having a magnetic permeability  $\mu_m$  less than 500 and a  
 12 saturation flux density greater than about 0.4T.  
 13

1 44. The method of claim 43 further comprising selecting dimensions for the  
 2 magnetic core which are related to the direction of the magnetic field and to  
 3 the magnetic permeability of the powdered soft magnetic material.  
 4

1 45. The method of claim 43 further comprising selecting relative dimensions for  
 2 the magnetic core which are related to the direction of the magnetic field and  
 3 to the magnetic permeability of the powdered soft magnetic material  
 4

1 46. The method of claim 43 wherein the powdered soft magnetic material is  
 2 conductive, the method further comprising selecting a maximum grain size for  
 3 the soft magnetic material to substantially prevent intragranular power loss of  
 4 said radio frequency magnetic field.  
 5

1 47. The method of claim 43 wherein an effective demagnetizing factor of the  
 2 magnetic core in the direction of the magnetic field substantially exceeds the  
 3 inverse magnetic permeability of the powdered soft magnetic material.  
 4

1 48. The method of claim 47, wherein the core has an effective permeability,  $\mu$ ,  
 2 less than 5, as defined by a first equation,

$$3 \quad \mu = 1 + (\mu_m - 1) / ((\mu_m - 1) \cdot D + 1),$$

4 wherein D, the demagnetizing factor can be estimated from an elliptic



5 equivalent of the cross-section of the core, as defined by a second equation,

6 
$$D = S_x / (S_x + S_y),$$

7 wherein  $S_x$  and  $S_y$  represent the elliptic equivalent dimensions in horizontal  
8 and vertical dimensions respectively, in a plane the core.

9

1 49. The method of claim 43, wherein the powdered soft magnetic material  
2 possesses a maximum magnetic permeability given a predetermined  
3 maximum RF antenna power loss.

4

1 50. The method of claim 43, wherein the magnet and the antenna possess an  
2 elongation direction, the radio frequency magnetic field and the static  
3 magnetic field being perpendicular to the elongation direction.

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